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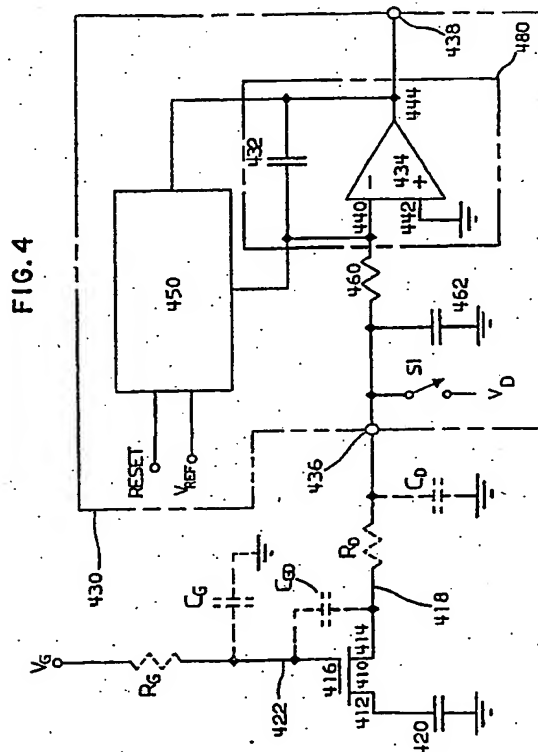
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(54) Method and apparatus for analog testing of thin film transistor arrays.

(57) The present invention relates to a sense circuit (430) for detecting charge on a TFT/LCD cell capacitor (420), which comprises a first, integrating circuit (480) attached to the TFT/LCD cell capacitor through a data line (418), wherein the data line is connected to the cell capacitance through a thin film transistor (410). The thin film transistor including a gate, a drain and a source, wherein the source (412) is connected to the cell capacitor and the drain (414) is connected to the data line. A first, gate supply voltage (V_G) adapted to drive the gate of the thin film transistor. And a reset circuit (450) adapted to reset the integrating circuit. This embodiment may further include means (S1) for charging said cell capacitor prior to measuring the charge.

The present invention further includes a method of testing a partially constructed electronic circuit, for example the cell of an LCD, prior to installation of the backplate. The partial circuit comprising an array of contact electrodes, for example cell pad electrodes being electrically connected to the contact electrodes. The method comprising the steps of providing the partial circuit with a test electrode, for example an adjacent data electrode extending alongside but spaced from at least a first contact electrode; and measuring the capacitance between the first contact electrode and the test electrode.

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METHOD AND APPARATUS FOR ANALOG TESTING OF THIN FILM TRANSISTOR ARRAYS

The present invention relates, in general, to a method and apparatus for testing Thin Film Transistor, Liquid Crystal Display Arrays and, more particularly to a method and apparatus for placing a charge on a TFT/LCD cell capacitor and measuring the charge retained on the capacitor after a brief period.

It is desirable to test all cells in a liquid crystal display (LCD) prior to assembling the array into a Liquid Crystal Display Panel. This eliminates alignment, assembly and filling costs for rejected arrays. A cell normally comprises a thin film transistor (TFT), and a pad which may be modelled electrically as one side of a capacitor. Thus, electrically, the cell appears to be a TFT with a series cell capacitance attached to its source. Since, it is extremely expensive and time consuming to test each cell in the array, individual cells, located at test sights on the border of the array are normally used to conduct preassembly tests. Because this test does not check for bus continuity, individual transistor functionality, or contact to the Indium-tin-oxide (ITO) pad, arrays that pass the this type of preassembly test may still fail to produce acceptable displays. It would, therefore, be advantageous to provide a method and apparatus for quickly and economically testing each cell in the array to assure that it is operational. It would also be advantageous if the method and apparatus provided information on the operational characteristics of individual cells.

Normally, when testing prior to assembly, the back plate of the display is not in place, which reduces the cell capacitance and makes measuring charge stored thereon more difficult.

Conventional methods of testing individual elements of the array involve mechanically probing the array. For example, it may be advantageous to probe the source and drain pads may be accessed using a mechanical probe. Once the source and drain pads are accessed, the status of individual TFT's may be determined. Unfortunately, this method of testing is extremely time consuming and may physically damage the array. Therefore, testing of display cell transistors is presently done of experimental, small area arrays using mechanically positioned probes.

The invention as claimed is intended to remedy these drawbacks. Therefore it is the object of the invention to test all transistors, ITO contacts, gate and drain lines on a large array without the top plate (counter-electrode) in place.

In one embodiment of the present invention a sense circuit for detecting charge on a TFT/LCD cell capacitor, comprises a first, integrating circuit

attached to the TFT/LCD cell capacitor through a data line, wherein the data line is connected to the cell capacitance through a thin film transistor. The thin film transistor includes a gate, a drain and a source, wherein the source is connected to the cell capacitor and the drain is connected to the data line. A first, gate supply voltage adapted to drive the gate of the thin film transistor. And a reset circuit adapted to reset the integrating circuit. This embodiment may further include means for charging said cell capacitor prior to measuring the charge, for example an adjustable supply voltage switchably attached to the data line.

More particularly, a thin film transistor test circuit apparatus is described, including an input terminal and an output terminal, an operational amplifier including non-inverting and inverting input terminals and an output terminal. The output terminal being connected to the output terminal of the test circuit and the non-inverting terminal being connected to a ground potential. An integrating capacitor is connected between the inverting terminal and the output terminal. A first switch is connected between a first potential and the test circuit input terminal. The test circuit being connected to inverting input terminal. A reset circuit is connected across the integrating capacitor, between the inverting input terminal and the test circuit output terminal.

The present invention further includes a method of testing a partially constructed electronic circuit, for example the cell of an LCD prior to installation of the backplate. The partial circuit comprising an array of contact electrodes, for example cell pad electrodes and an array of address electrodes, for example gate electrodes. The address electrodes being electrically connected to the contact electrodes. The method comprising the steps of providing the partial circuit with a test electrode, for example an adjacent data electrode extending alongside but spaced from at least a first contact electrode; and measuring the capacitance between the first contact electrode and the test electrode.

A method of testing thin film transistors having a gate, a source and a drain, using the test circuit described above, wherein the gate is connected to a gate terminal through a gate line. The drain is connected to a drain terminal through a data line. The source connected to a liquid crystal cell capacitor pad through a source terminal. The method comprising a series of steps including resetting the integrator, closing the third switch, and closing the first switch to initiate the process. Waiting a first predetermined time period, corresponding to a time constant of the data line. Applying a voltage to the

gate terminal sufficient to bias the transistor on. Waiting a second predetermined time period corresponding to the test time period (i.e. the charge time of the cell) for the thin film transistor to charge the cell capacitance. Applying a voltage to the gate terminal sufficient to bias the transistor off. Once the transistor is biased off, it is held off for a period of time corresponding to the hold time of a cell during normal operation. During this period, the test circuit is reset to prepare the integrator to measure the charge stored on the cell. The charge is measured by applying a voltage to the gate sufficient to turn the transistor on. Waiting a predetermined time which is at least sufficient to transfer charge from the cell capacitor to the charge integrating operational amplifier. Applying a voltage to the gate sufficient to turn the transistor off. Waiting a predetermined time, corresponding to the RC time constant of the gate line. Sampling the voltage at the output node.

It is a further advantage of the invention to test each individual element of the array and obtain useful analog information without physically contacting any portion of the cell being tested.

The novel features of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

- Figure 1 illustrates a typical TFT/LCD cell;
- Figure 2 illustrates a schematic diagram of one embodiment of the present invention, including a schematic diagram of a typical TFT/LCD cell;
- Figure 3 illustrates a timing diagram for one embodiment of the method of the present invention;
- Figure 4 illustrates a schematic diagram of one embodiment of the present invention, including a schematic diagram of a typical TFT/LCD cell;
- Figure 5 illustrates a timing diagram for one embodiment of the present invention;
- Figure 6 illustrates a further embodiment of the present invention; and
- Figure 7 illustrates a typical TFT/LCD cell including a storage capacitor.

The present invention involves a method of characterizing individual cells within a Thin Film Transistor/Liquid Crystal Display (TFT/LCD) array. The method provides an indication of the state of each transistor along with information on the threshold voltage and transconductance of the transistor. In addition, the leakage current and C_{GS} of

each cell may be measured. The present method is useful for failure analysis, process variation and production line tests.

In Figure 1, a Thin Film Transistor (TFT) 110 includes source contact 112, drain contact 114 and gate contact 116. Source contact 112 supplies Liquid Crystal Display (LCD) pad 120 which may be comprised of, for example, Indium Tin Oxide (ITO). Drain contact 114 is connected to data line 118. Gate contact 116 is connected to gate line 122. The combination described is referred to as a cell. A TFT/LCD array comprises many such cells. Each cell may be individually accessed and tested. Gate line 123 and data line 119 may be used to access a unique cell site not illustrated in Figure 1.

Figure 2 is a schematic of one preferred embodiment of the present invention attached to a typical TFT/LCD cell. A TFT/LCD cell, similar to the cell described with respect to Figure 1, is illustrated in Figure 2 in schematic form. In Figure 2, a Thin Film Transistor (TFT) 210 includes source contact 212, drain contact 214 and gate contact 216. Source contact 212 supplies the Liquid Crystal Display (LCD) pad which is represented schematically in Figure 2 by capacitor 220.

It will be noted that some TFT/LCD cells include storage capacitance in parallel with the LCD pad (see capacitor 721 in Figure 7). These storage capacitors may, therefore, contribute to the capacitance of capacitor 220. Drain contact 214 is connected to data line 218. Gate contact 216 is connected to gate line 222. C_{GS} in Figure 2 represents the gate-source capacitance of transistor 210.

To test individual cell transistors without the presence of the front plate, it is necessary to detect the magnitude of charge stored on the parasitic capacitance of LCD pad 120. Consider the individual cell detail of a typical large display array as shown in FIG. 1. In the cell illustrated in Figure 1, LCD pad 120 is the only connection to the transistor source. Parasitic capacitance from the pad to the adjacent gate and drain lines are included in the capacitor 220 as illustrated in Figure 2.

A sensing circuit 230, according to the present invention, which is capable of measuring small charge quantities with good resolution, is illustrated in FIG. 2. In this embodiment, operational amplifier 234, capacitor 232 and switch S3 form a resettable integrator. Operational amplifier 234 includes inverting input 240 and non-inverting input 242. Non-inverting input 242 is connected to ground potential. Inverting input 240 is connected to operational amplifier output 244 through integration capacitor 232 and switch S3. Output 244 is connected to output terminal 238. Switch S2 connects inverting input 240 to input terminal 236. Switch S1 connects input terminal 236 and switch S2 to supply voltage V_D . Input terminal 236 connects sensing circuit 230

to data line 218. Gate line 222 connects V_G to gate 216 of transistor 210. Switches S1 and S2 are used to control the voltages applied to drain contact 214. Switch S3 is used to reset integrator 280. R_D represents the distributed resistance of data line 218. C_D represents the distributed capacitance of data line 218. R_G represents the distributed resistance of gate line 222. C_G represents the distributed capacitance of gate line 222. C_{GD} is the gate line capacitance of transistor 210. It will be noted that the ground connection for capacitor 220, which is necessary for the present invention, may be provided by, for example, grounding adjacent data line 123 and/or adjacent gate line 119 in Figure 1. This is equally true for the embodiment illustrated in Figures 4 and 6.

In one embodiment of the method of testing a TFT/LCD cell according to the present invention, the circuit of FIG. 2 can be used to determine the functional quality of a cell, i.e. the cell's ability to store charges. Figure 3 is a timing diagram for a method of testing a TFT/LCD cell according to the present invention using the embodiment of the present invention illustrated in Figure 2.

Figure 3 illustrates a test sequence according to one embodiment of the present invention. The timing diagram illustrated in Figure 3 indicates the sequence of signals applied to the switches and voltage sources in Figure 2. Initially, that is prior to time T1 in Figure 3, switch S1 is open, switch S2 is open, switch S3 is open, V_G is at approximately ground potential and V_D is at approximately ground potential. At time T1, S3 is closed, resetting the output of sense amplifier 230 to zero. Further, at time T1, V_D is set to a value sufficient to charge capacitor 220 when transistor 210 is on (e.g. the maximum data line voltage which would be used to drive the data line during normal operation of the display). In conventional displays, the data line voltage may be approximately 10 volts. At time T2, S1 is closed, connecting V_D to data line 218, and biasing drain 214. At time T3, V_G is set to a value sufficient to turn on transistor 210, for example a value which exceeds five times the threshold voltage of transistor 210 (e.g. 12 volts), thus biasing gate contact 216 through gate line 222 and turning on transistor 210. At time T4, V_G is reduced to a voltage below that required to turn on transistor 210, reducing the voltage supplied to gate contact 216 through gate line 222, and turning off transistor 210. At time T5, V_D is reduced, for example, to approximately ground potential, thus discharging the charge on the distributed capacitance (C_D) of the data line. At time T6, switch S1 is opened, to disconnect voltage source V_D from the data line. At time T7, S2 is closed, connecting transistor 210 to operational amplifier 234, thus setting sense amplifier 230 up for a sense operation. At time T8,

switch S3 is opened to allow the current from data line 218 to begin charging capacitor 232. At time T9, V_G is increased to a voltage sufficient to turn on transistor 210. At time T10, V_G is reduced to a voltage sufficient to turn off transistor 210.

In the embodiment of the invention illustrated in Figure 3, the period between time T9 and T10 is referred to as the integration period. In order to ensure accuracy of the test, this period will normally be at least four times the time constant of the cell. The cell time constant may be approximated by, for example, measuring the source to drain resistance R_{DS} and cell capacitance (capacitor 220 in Figure 2) of a test cell. During the integration period, S2 is closed and S1 is open, thus operational amplifier 234 holds the drain line at approximately ground potential due to its virtual ground between inverting input 240 and non inverting input 242 of operational amplifier 242. Therefore, during this period, the charge transferred to capacitor 232 is substantially equal to the charge removed from capacitor 220. Because inverting input 240 to operational amplifier 234 is a virtual ground, no charge is accumulated on drain line distributed capacitance C_D . This capacitance, along with drain line distributed resistance R_D , will, however, increase the time constant (i.e. the time required to charge capacitor 232 and discharge capacitor 220) and, thus the integration period.

During the integration period, the voltage at output terminal 238 changes due to the charge required to compensate for the in gate voltage across C_{GD} and the charge removed from capacitor C2 20 when the gate is biased on at T9. However, at T10, transistor 210 is turned off by reducing voltage V_G which removes the charge from C_{GD} and reduces the voltage at output terminal 238 as illustrated in Figure 3. Therefore, after time T10, the voltage at output terminal 238 will be substantially proportional to the charge stored on capacitor 220 at the end of the hold period (T_9). The output voltage may be converted to a digital word using an analog to digital converter and used to analyze various parameters of the cell. This test may be repeated a number of times for each individual cell to average out any transient errors. In addition, by selecting the appropriate gate and data lines, any cell in an array may be tested by accessing the external pads of the display. It is not necessary to mechanically access individual cells.

If a sense circuit is connected to every data line on an array, all of the transistors on a given gate line can be tested simultaneously. To check for basic function on each requires approximately 1 millisecond. Therefore, using the method of the present invention, a 1000 by 1000 array can be tested in 1 second.

It will be recognized that a portion of the volt-

age present at output terminal 238 after time T10 is attributable to parasitic capacitance in the test fixture. However, the effect of the parasitic capacitance may be measured and subtracted out of the voltage present at output terminal 238 to obtain a more accurate approximation of the charge on capacitor 220. The effect of the parasitic capacitance may be measured, for example, by repeating the test described above with respect to Figure 3, omitting the steps required to turn on transistor 210 during the period of T3 to T4. Thus, at time T10, the voltage at output node 238 would represent the charge stored on any parasitic capacitance in the test fixture.

The test described above with respect to Figure 3, will provide an indication of the functionality of the cell being addressed. By varying some of the time periods, a number of other important parameters of the cell may be defined. For example, the LCD leakage resistance is an important parameter which may be derived by plotting the measured output voltage as a function of the hold period. The period T4 to T9 is defined as the hold period and represents the period of time that the charge is held on an individual cell during a frame time in an actual display. It will be noted that the period is varied by extending the time between T4 and T9. The times T4 to T5, T4 to T6, T4 to T7 and T4 to T8 remain fixed as does the time T9 to T10. Since the capacitance of the cell may be determined by, for example, measuring the capacitance of a test cell, a logarithmic plot of the output voltage as a function of the hold time will provide an indication of the leakage resistance.

In a similar manner, the cell charging time may be determined by varying the period between time T3 and time T4 to obtain a plot of the output voltage as a function of the gate on time (T3 to T4). Since the cell capacitance may be determined as described above, a logarithmic plot of the output voltage after T10 as a function of the gate on time provides an indication of the cell charging time, which in turn, provides an indication of the drain to source resistance R_{DS} of the cell transistor.

Similarly, by varying the voltage on the data line V_D and measuring the output voltage over a number of interactions of the test, it is possible to derive the threshold voltage of the transistor in the cell from a plot of output voltage as a function of data line voltage.

The circuit of FIG. 2 may be susceptible to transient currents exiting when S3 is opened at time T8. This effect may be overcome by sampling the voltage at output terminal 238 just prior to beginning the sense operation (i.e. just prior to time T9) and subtracting that voltage from the voltage at the end of the sense time (after T10), doubling the number of analog to digital (A/D) conversions re-

quired. In addition, the output range of the circuit illustrated in Figure 2 may not be compatible with most commercial A/D converters (0 to +5V). That is, its output may be too low to be converted with acceptable accuracy. To eliminate the uncertainty resulting from transients on S3, and increase the voltage at the output terminal 238, a further embodiment of the present invention has been developed and is illustrated in Figure 4.

Figure 4 is a schematic of one preferred embodiment of the present invention attached to a typical TFT/LCD cell. The TFT/LCD cell, similar to the cell described with respect to Figure 1, is illustrated in Figure 4 in schematic form. In Figure 4, a Thin Film Transistor (TFT) 410 includes source contact 412, drain contact 414 and gate contact 416. Source contact 412 supplies the Liquid Crystal Display (LCD) pad which is represented schematically in Figure 4 by capacitor 420. Drain contact 414 is connected to data line 418. Gate contact 416 is connected to gate line 422. C_{GD} in Figure 4 represents the gate-source capacitance of transistor 410.

In the embodiment of the present invention illustrated in Figure 4 reset control 450 is used in place of switch S3. The reset level for analog integrator 480 is controlled by reset control 450 which includes a reset reference voltage (V_{REF}) and a comparison circuit. V_{REF} provides sense range control. In this embodiment, switch S2 is replaced by resistor 460 and capacitor 462. R_D represents the distributed resistance of drain line 418, while C_D represents. In a display comprising one million cells arrayed in rows and columns of 1000 cells, distributed capacitance may approach about 1nF.

In the embodiment of Figure 4, operational amplifier 434, capacitor 432 and reset control 450 form a resettable integrator. Operational amplifier 434 includes inverting input 440 and non-inverting input 442. Non-inverting input 442 is connected to ground potential. Inverting input 440 is connected to operational amplifier output 444 through integration capacitor 432 and reset control 450. Output 444 is connected to output terminal 438. Resistor 460 connects inverting input 440 to input terminal 436. Switch S1 connects input terminal 436 resistor 460 and capacitor 462 to a supply voltage V_D . Input terminal 436 connects sensing circuit 450 to data line 418. Switches S1 and S3 are used to control the voltages applied to drain contact 414.

Figure 5 illustrates a timing diagram for one embodiment of the method of the present invention, using the apparatus illustrated in Figure 4. The following is a description of a test according to one method of the present invention illustrated in Figure 5. Thus, all times referred to in the following description relate to the times illustrated in Figure 5. Prior to T1, switch S1 is open, switch S3 is open,

V_G is at approximately ground potential and V_D is at approximately ground potential. The first step in a single charge test is to stabilize the data voltage at the value desired for the test. Thus, at T1, the data voltage V_D is set to a value sufficient to charge capacitor 420. Data voltage V_D should, preferably, be adjustable over full range of values used in display operation. For a typical TFT/LCD, using a twisted nematic liquid crystal, this data voltage may range from approximately zero to eleven volts. In some displays the data voltage may reach approximately fourteen volts. At time T1, transistor 410 is held OFF by the voltage at gate 416 (V_G), switch S1 is open to disconnect the data line from data voltage V_D , and switch S3 is closed to reset output 444 of integrator 480 to a preselected level. This preselected level is defined by V_{REF} and is approximately. At time T2, switch S1 is closed, connecting data voltage (V_D) to data line 418. This state is held for at least a timeconstant $\tau_{DATALINE}$ of data line 418. The data line time constant $\tau_{DATALINE}$ ($\tau_{DATALINE} = R_D C_D$) where R_D is resistor is the dataline resistance and C_D is the dataline capacitance.

At time T3, gate voltage V_G is turned on. The gate ON voltage should be greater than the threshold voltage of the thin film transistor to insure that the transistor channel will turn on, conversely, the gate OFF voltage should be chosen to be less than the threshold voltage of the transistor to insure that the transistor channel is biased off. The width of the gate pulse should be greater than the timeconstant of a gate line ($\tau_{GATELINE} = R_G C_G$). At time T4, the end of the gate pulse, the tester enters a hold time (T4 to T8), during this period the charge that has been transferred to the cell is stored on the cell capacitance. This period emulates an actual display, where charge is stored on the cell capacitance for a line time. For a display with N gate lines, and with M refresh cycles per second, the gate pulse width would be $\tau_{GATEPULSE} = 1/(N * M)$, and the hold time would be approximately $1/M$. for a typical 1000 gate line display operating at 100 Hertz refresh, the gate pulse width would be 10 microseconds, and the hold time would be 10 milliseconds. During the hold time, the data voltage V_D is returned to zero volts at time T5. At time T6, the data line is disconnected from the data voltage source by opening switch S1. In order to ensure proper operation, T6 is delayed from the trailing edge of the gate pulse by at least one gate line timeconstant ($\tau_{GATELINE}$). Since data line 418 is connected to inverting input 440 of operational amplifier 480, which is a virtual ground, the voltage on the data line relaxes to ground which requires at least 1 data line time constant ($\tau_{GATELINE}$). After the data line voltage has relaxed to ground, at time T7, capacitor 432 is released from the reset voltage level maintained by reset control 450. Thus, at time

T7, integrator 434 will begin to integrate the current into the inverting input of the operational amplifier. At T8, the end of the hold time, the gate voltage is turned on to a level greater than the threshold voltage of the thin film transistor, insuring that the transistor channel ohmically connects the cell capacitance to the data line. The gate voltage is held for several cell discharge time constants to insure that all of the charge on the cell capacitance can return to the operational amplifier virtual ground and be integrated by capacitor 432. At T9, gate voltage V_G is reduced, turning off transistor 410. This voltage may be measured immediately, however, it is normally better to wait for at least a gate line time constant ($\tau_{GATELINE}$). The difference in voltage between the output just before time T8 and the output after time T9 of the analog to digital converter is substantially proportional ($Q_{CELL} = (V_{AD} - V_{RESET}) C_1$) to the charge stored on the cell capacitance 420.

The gate ON time (T3 to T4) can be varied to determine the amount of charge that is transferred to the cell. This data can be used to calculate the charging time constant for a cell.

Reset circuit 450 is designed to hold the output of the operational amplifier at a fixed potential (V_{RESET}) during the period T1 to T7. The output of operational amplifier 434 is controlled by the integrated current into the inverting input after T7.

Figure 6 is a schematic of a further preferred embodiment of the present invention. The data lines of the TFT/LCD array to be tested are connected to the test circuit through connector 690. Analog multiplex switch S4 is used to select an individual data line to be connected to the test circuit through line 692. Analog multiplex switch S4 may be, for example a MUX16 analog multiplex switch from Precision Monolithic Integrated Circuits. The data lines are further connected through connector 690 to lines 694 which are individually connected to switches S5. Switch S5 may be, for example a SW202 analog switch from Precision Monolithic Integrated Circuits. Since the test circuit in Figure 6 is connected to only one data line at a time, switches S5 may be used to ground the nonselected switches, thus ensuring a good ground reference for the cell capacitance even when the backplate is removed. The data line selected by switch S4 is not grounded since its S5 switch is held open during the test period. The data line selected by S4 is connected to V_D through switch S1 and to operational amplifier 634 through resistor 660. Resistor 660 may be, for example, 10 thousand ohms. Operational amplifier 634 may be, for example, an OP-17. The non-inverting input 642 of operational amplifier 634 is connected to ground potential, thus creating a virtual ground at inverting input 640. Inverting input 640 is connected to ca-

capacitor 632 which is also connected to operational amplifier output 644 and acts as an integrating capacitor. Capacitor 632 may be, for example, on the order of 5 picofarads. However, its size will normally be determined by the desired amplitude of the integrator output voltage. Operational amplifier 634 in combination with capacitor 632 comprise integrator 680. Since the voltage across capacitor 632 must be reset after each test, reset circuit 650 is provided. Reset circuit 650 has two input signals, V_{REF} and RESET. Since switch S3 is controlled by the RESET signal, the level of the RESET signal must be sufficient to drive S3. S3 may be, for example, a SW202 from Precision Monolithic Integrated Circuits which requires normal TTL levels. V_{REF} is a voltage level which supplies a reference signal to the inverting input of operational amplifier 652. Operational amplifier 652 may be, for example, a OP-16. V_{REF} is also connected to ground potential through capacitor 659. Capacitor 659 acts as a noise filter and may be, for example, 0.1 microfarads to effectively remove AC noise from the reference voltage. The non-inverting input of operational amplifier 652 is connected to one side of capacitor 632 and to output 644 of operational amplifier 634. The output of operational amplifier 652 is connected to resistor 651 which in turn is connected to one terminal of switch S3. Resistor 651 may be, for example 4.99 thousand ohms. The other terminal of S3 is connected to ground through resistor 657 and to capacitor 632 through the parallel combination of resistor 654 and capacitor 655. Resistor 657 may be, for example, 4.02 thousand ohms. Resistor 654 may be, for example, 3.01 thousand ohms. Capacitor 655 may be, for example, 3 picofarads. Thus, the combination of reset circuit 650 and integrator 680 form a resettable integrator.

It will be apparent to those of skill in the art that reset circuit 650, described with respect to Figure 6 may be substituted for reset circuit 450 in Figure 4, as a means of implementing the embodiment of Figure 4.

In short, the method of the present invention is designed to store charge in the active area of a particular TFT/LCD cell. The electrical characteristics of the cell may then be calculated by reading the charge stored on the active area after a period of time. More particularly, in a backplane tester according to one embodiment of the present invention charge is stored on the cell through a series of switches while an operational amplifier is employed in an inverting, integrating mode to detect the charge stored on the cell. When utilized according to the method of the present invention, this arrangement provides a means of reliably and accurately measuring the charge on the liquid crystal pad capacitance.

In the method of the present invention, the measurement resolution may be improved by sequencing the test steps to minimize the effect of gate to source coupling through C_{GS} coupling. The resolution may be further improved by subtracting out the parasitic capacitance introduced by the test fixture. This parasitic capacitance may be measured by turning off the transistor during the charge cycle and measuring the output voltage. Since the output voltage is proportional to the parasitic capacitance of the test fixture, that voltage may be subtracted off the voltage measured during normal testing. In the method of the present invention, the resolution may be further improved by running the test several times and averaging the output voltages measured to remove random error from the measurements.

In LCD displays which do not use storage capacitors (as in Figure 1) the primary capacitance measured by the method according to the present invention is the pad to adjacent gate line capacitance. It is desirable to minimize this capacitance in the design of conventional TFT/LCD's to increase the charging time. Unfortunately, this reduces the accuracy of the test method according to the present invention. In order to increase the measured charges, utilizing the method of the present invention, the per capacitance can be doubled by testing alternate columns of devices, thus utilizing the capacitance to the adjacent drain line as well as that of the adjacent gate line. For an 80 pixel per inch display and using a gap of 10 microns, the total parasitic capacitance may be expected to be approximately 0.05 pF, and for a 160 pixel per inch display and using a gap of ten microns, the capacitance would be expected to be approximately 0.025 pF.

In one preferred embodiment of the present invention, a sixteen pole analog multiplexor is used to select one out of sixteen data lines to test. The other fifteen data lines are grounded using analog switches. Thus the output voltage will be proportional to the charge stored on a one cell along the selected data line. The cell is determined by selecting the gate line.

In Figure 6, switch S3 may be an analog switch (typically an SW202 from Precision Monolithic Incorporated, PMI) to either connect or disconnect the output node of an operational amplifier (typically an OP-16 from PMI) to the inverting input of the integrating operational amplifier (typically an OP-17 from PMI), the non-inverting output of the OP-16 operational amplifier is connected to the output of the OP-17, the inverting input of the OP-16 is connected to the V_{REF} . When S2 is closed the potential across the integrating capacitor, C1, is held fixed at V_{RESET} , when S2 is open the integrating capacitor is allowed to integrate the current

from the data line of the display.

An analog method of testing TFT arrays cell capacitance for use in LCD displays, has been described. This method provides significant advantages over conventional digital test methods. In addition, techniques have been described to minimize parasitic effects and noise induced errors. Finally, test sequences have been described which utilize the method according to the present invention to test for GO/NOGO, threshold voltage, transconductance, leakage current, and C_{GS} .

It is known that, a photosensitive element such as an amorphous silicon resistor, could be added to the LCD cell to charge or discharge the LCD capacitor (see USP 4,819,038). It will then be apparent that a circuit according to the present invention could be used to detect the change in charge on the capacitor. Thus, the present invention could be used to construct an input device.

Claims

1. A sense circuit (230, 430) for detecting charge on a thin film transistor/liquid crystal display (TFT/LCD) cell capacitor, comprising:
 - a first, integrating circuit (280, 480) attached to said TFT/LCD cell capacitor (220, 420) through a data line (218, 418), wherein said data line is connected to said cell capacitance through a thin film transistor (110, 210, 410);
 - said thin film transistor including a gate (216, 416), a drain (214, 414) and a source (212, 412), wherein said source is connected to said cell capacitor and said drain is connected to said data line;
 - a first, gate supply voltage (V_G) adapted to drive said gate of said thin film transistor; and
 - a reset means (S3, 450) adapted to reset said integrating circuit.
2. A sense circuit according to claim 1 wherein said integrating circuit comprising an operational amplifier (234, 434) including an output, an inverting input and a non-inverting input and a capacitor (232, 432) connected from said inverting input to said output of said operational amplifier; and
 - said reset means is connected across said capacitor.
3. A sense circuit according to claim 2 wherein said reset means comprises a switch.
4. A sense circuit according to claim 2 wherein said reset means (650) comprises a second operational amplifier (652) connected to a switch (S3), wherein said operational amplifier includes an inverting input, a non-inverting, and an output;
 - one side of said switch being connected to said inverting input (640) of said first operational amplifier and an opposite side of said switch being connected to said output of said second operational amplifier;
 - said inverting input of said second operational amplifier being connected to a reference voltage;
 - said non-inverting input of said second operational amplifier being connected to a ground potential;
 - said switch including an enable input, wherein, said enable input opens or closes said switch; and
 - said enable input being connected to a reset signal.
5. A circuit according to any one of the preceding claims further including means (S1, V_D) for depositing charge on said cell at predetermined times.
6. A circuit according to claim 5 wherein said means for depositing charge comprises a resettable switch connecting a variable voltage supply to said data line.
7. A circuit according to any one of the preceding claims wherein a switch (S2) is connected between said integrating circuit and the sense circuit input terminal (236, 436).
8. A method of testing a partially constructed electronic circuit, said partial circuit being combinable with a remainder circuit to form a complete circuit, said partial circuit comprising an array of contact electrodes and an array of address electrodes, said contact electrodes being electrically connectable to the remainder circuit, said address electrodes being electrically connected to the contact electrodes, said method comprising the steps of:
 - providing the partial circuit with a test electrode extending alongside but spaced from at least a first contact electrode; and
 - measuring the capacitance between the first contact electrode and the test electrode.
9. A method as claimed in claim 8, wherein the address electrode is electrically connected to and addressable by energizing a unique pair of address electrodes associated with that contact electrode; and the step of measuring comprises measuring the capacitance between the first contact

electrode and an address which is not electrically connected to or associated with the first contact electrode.

10. A method as claimed in claim 9, further comprising the steps of:

separately measuring the capacitance between each contact electrode and an address electrode which is not electrically connected to or associated with the contact electrode.

11. A method as claimed in claim 10, wherein each contact electrode comprises an electrode pad and a switch having first and second inputs and an output, said first input being electrically connected to one address electrode associated with the contact electrode, said second input being electrically connected to the other address electrode associated with the contact electrode said output being electrically connected to the electrode pad; and each measuring step comprises: energizing the address electrodes associated with the contact electrode so as to store electric charge on the electrode pad; and measuring the electric charge stored on the electrode pad.

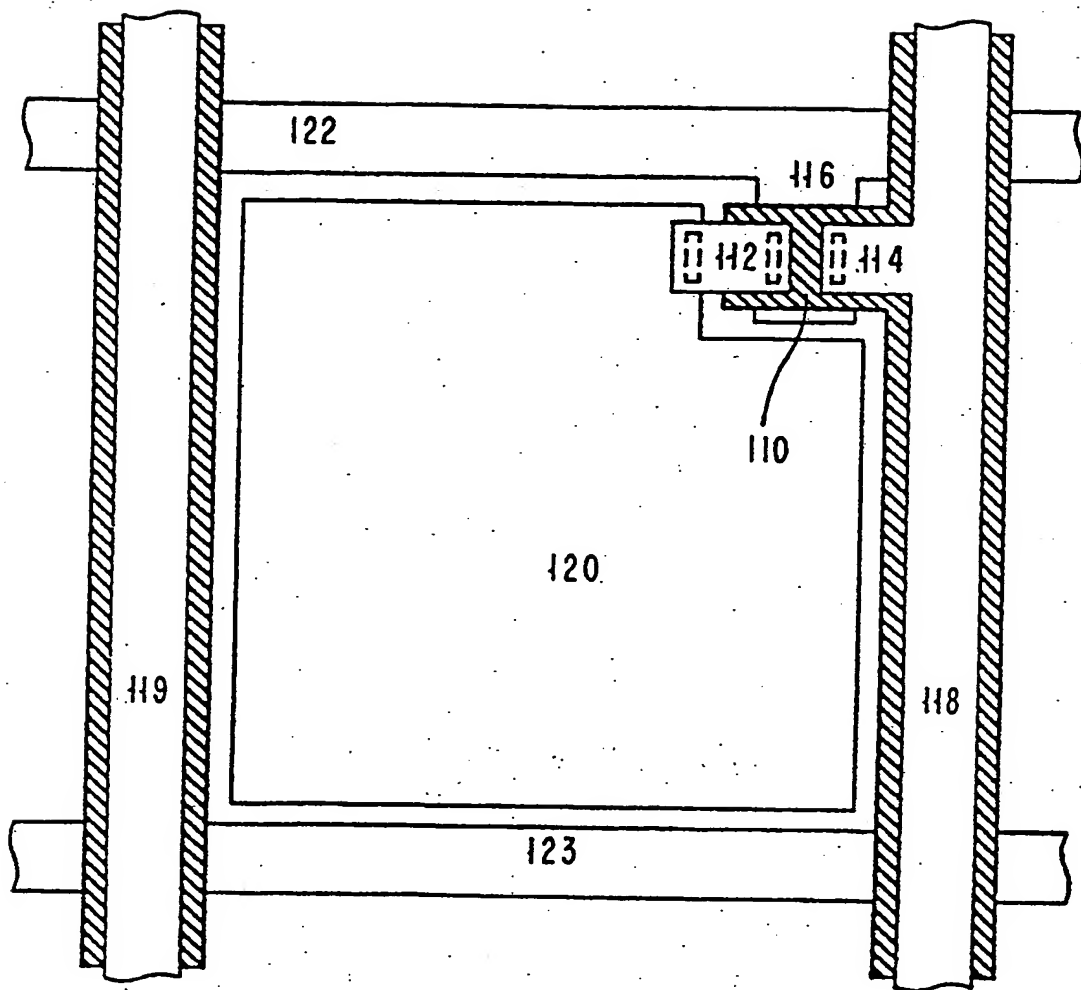
12. A method of testing a TFT/LCD including a cell comprised of a cell capacitor, and a thin film transistor including a gate, a source and a drain, wherein said drain is connected to said cell capacitor, using a sense circuit comprising an integrator means and reset means wherein said integrator means is selectively coupled to said drain through a data line, said method comprising the steps of:

turning off said thin film transistor by applying a first determining gate voltage to said gate;
resetting said integrator using said reset circuit;
raising the voltage on said drain to a value sufficient to charge said cell capacitor;
applying a second predetermined gate voltage to said gate sufficient to turn on said transistor;
waiting a first predetermined time period sufficient to charge said cell capacitor to a predetermined test value;
applying said first gate voltage to said gate to turn said transistor off;
waiting a second predetermined period of time;
lowering said voltage on said drain to ap-

proximately ground potential during said second period of time;
disconnecting said voltage to said gate to turn said transistor on;
waiting a third predetermined period of time;
applying said first gate voltage to said gate to turn said transistor off;
measuring a potential at an output of said integrator means.

13. A method according to claim 12 wherein: said first predetermined time is at least one time constant of said gate line;
said second predetermined time is at least a period of time equal to a hold time;
said third predetermined time is at least two cell discharge time constants.

FIG. 1



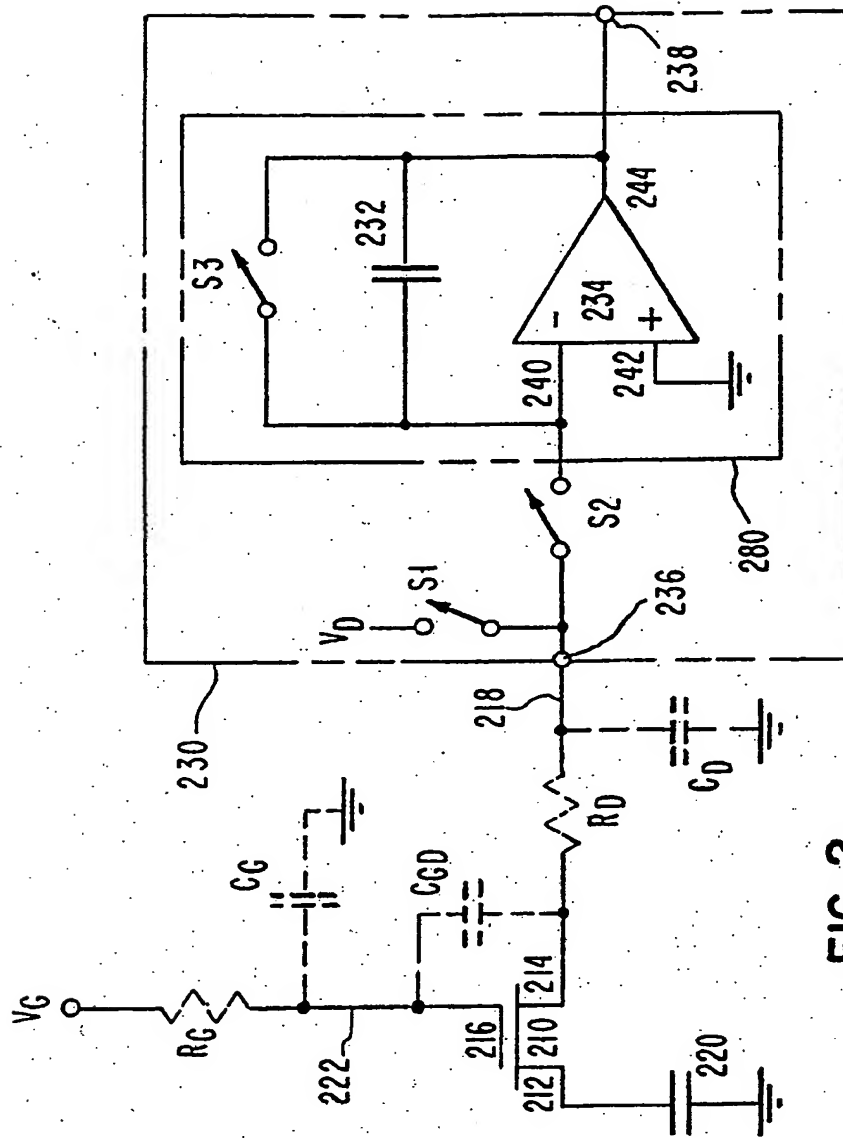


FIG. 2

FIG. 3

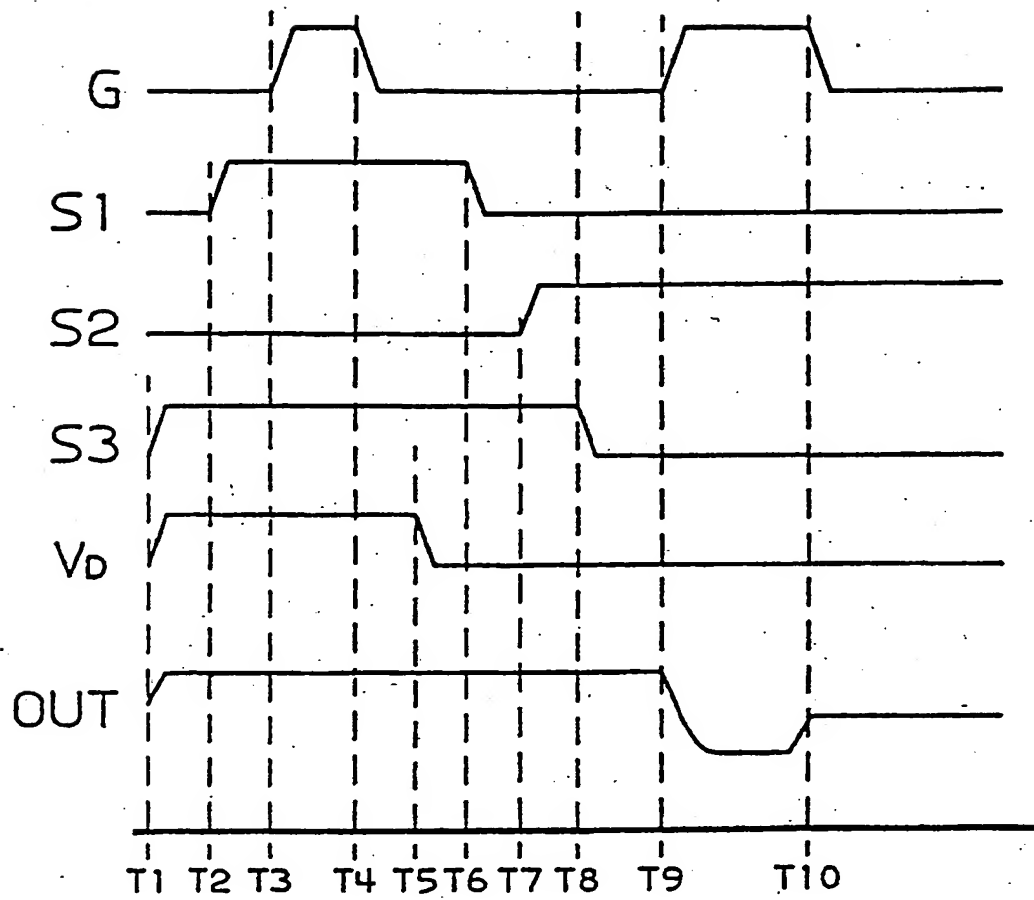


FIG. 4

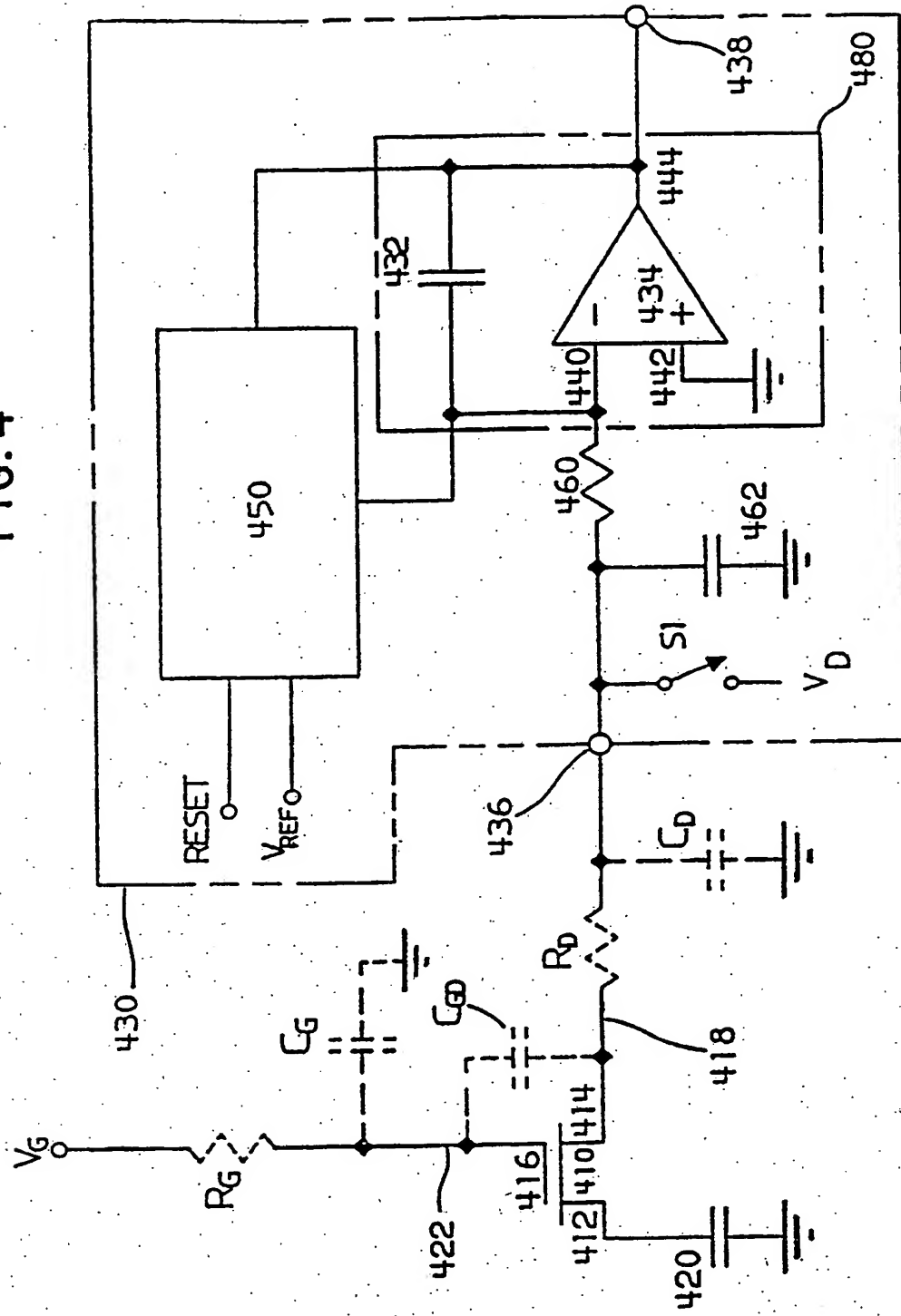


FIG. 5

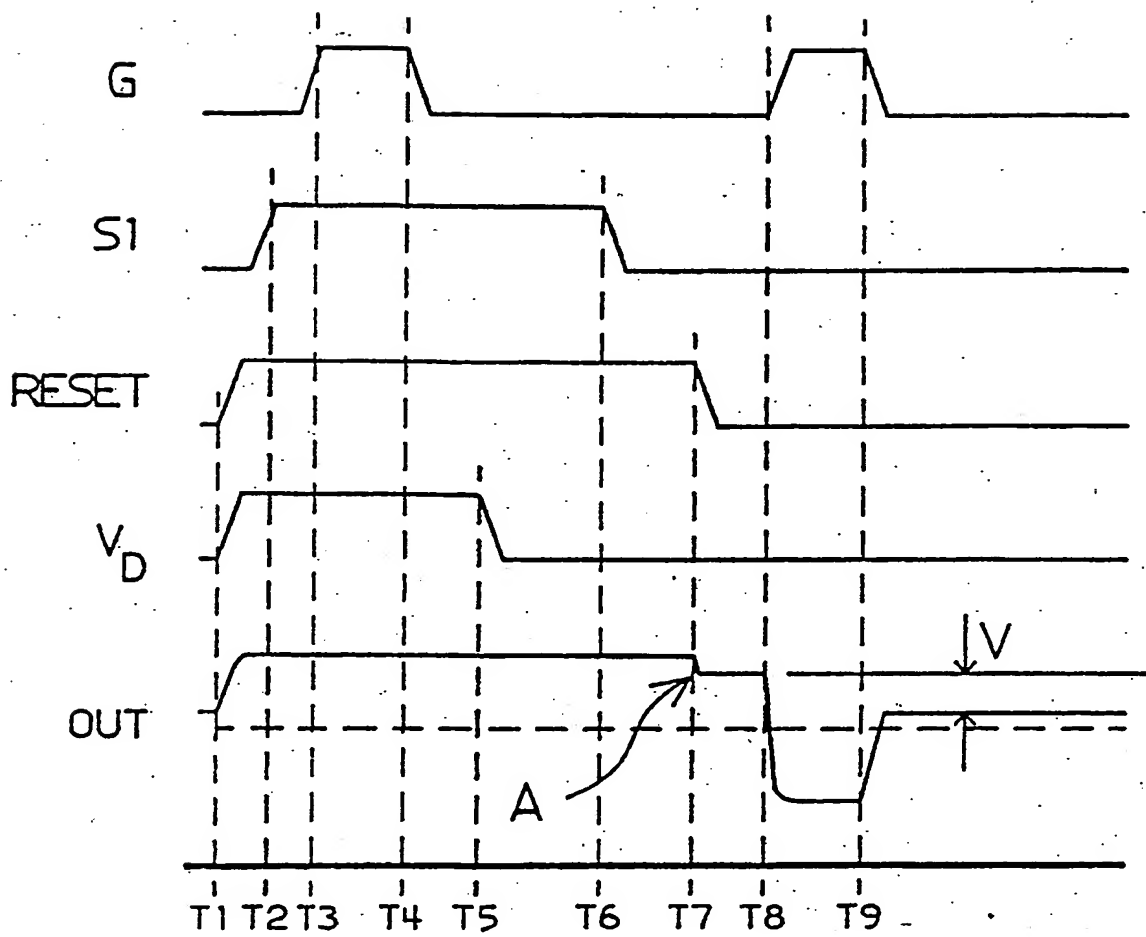


FIG. 6

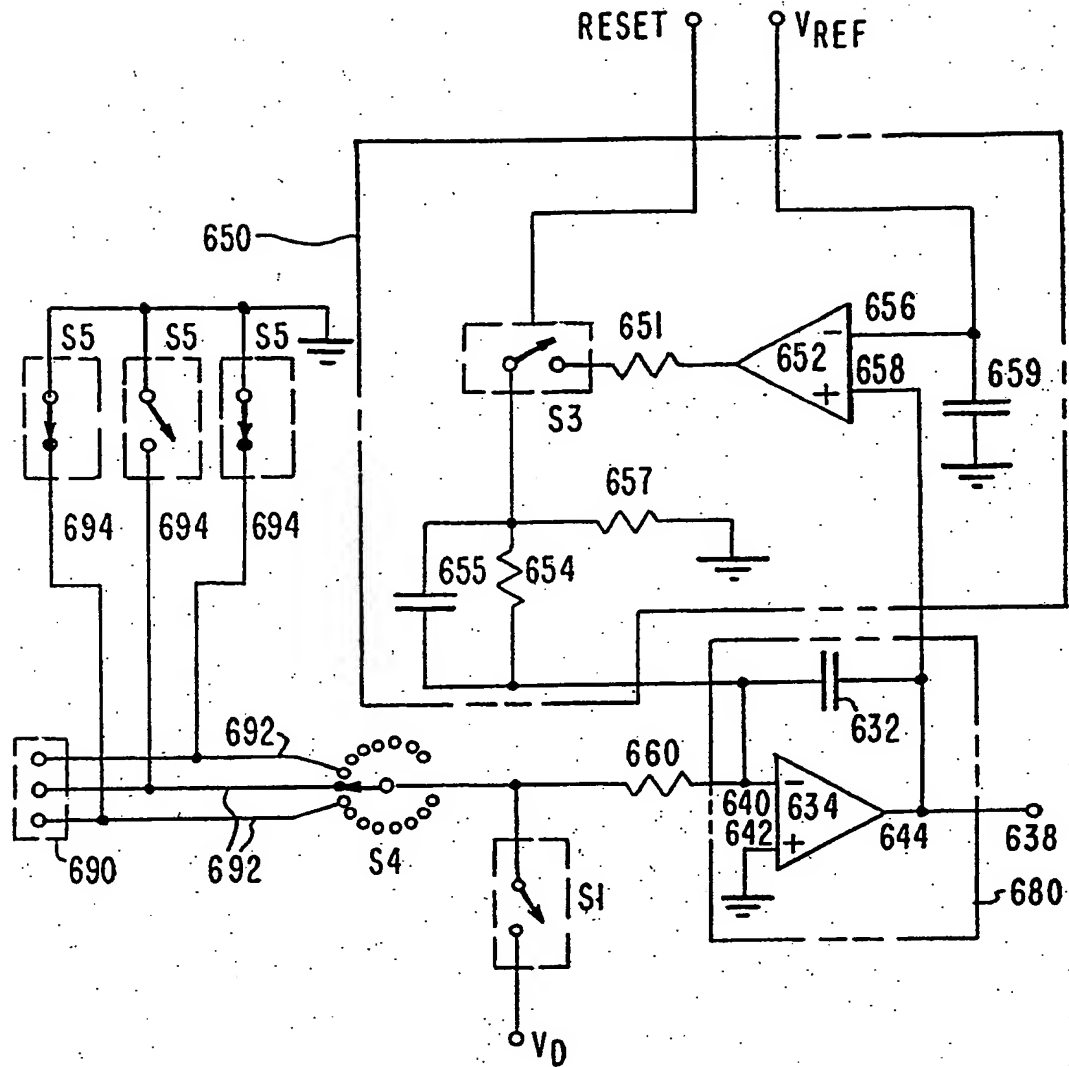


FIG. 7

